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(54) **Improvements relating to scanning electron and scanning optical microscopes**

(57) A hybrid instrument operable as a scanning electron microscope (SEM) or a scanning optical microscope comprises a scanning electron microscope provided additionally with a luminescent device (12) emitting light in response to incident electrons and which is removably insertible into the scanning electron beam (3) which is focused on the device to produce light therefrom. Removable means such as a lens 14 focuses scanned light (15) on a specimen (4) to be studied. Usually the instrument will have at least one additional detector which is responsive to a signal from the specimen in response to the incident light beam and which is connected to the image signal processing and display system of the SEM. The luminescent device (12), the lens (14), and the detector or detectors may be carried by a conversion specimen stage which can be interchanged with the normal specimen stage of the SEM when the instrument is to be used as a scanning optical microscope. The specimen (4) may lie outside the vacuum chamber.

Fig. 2.

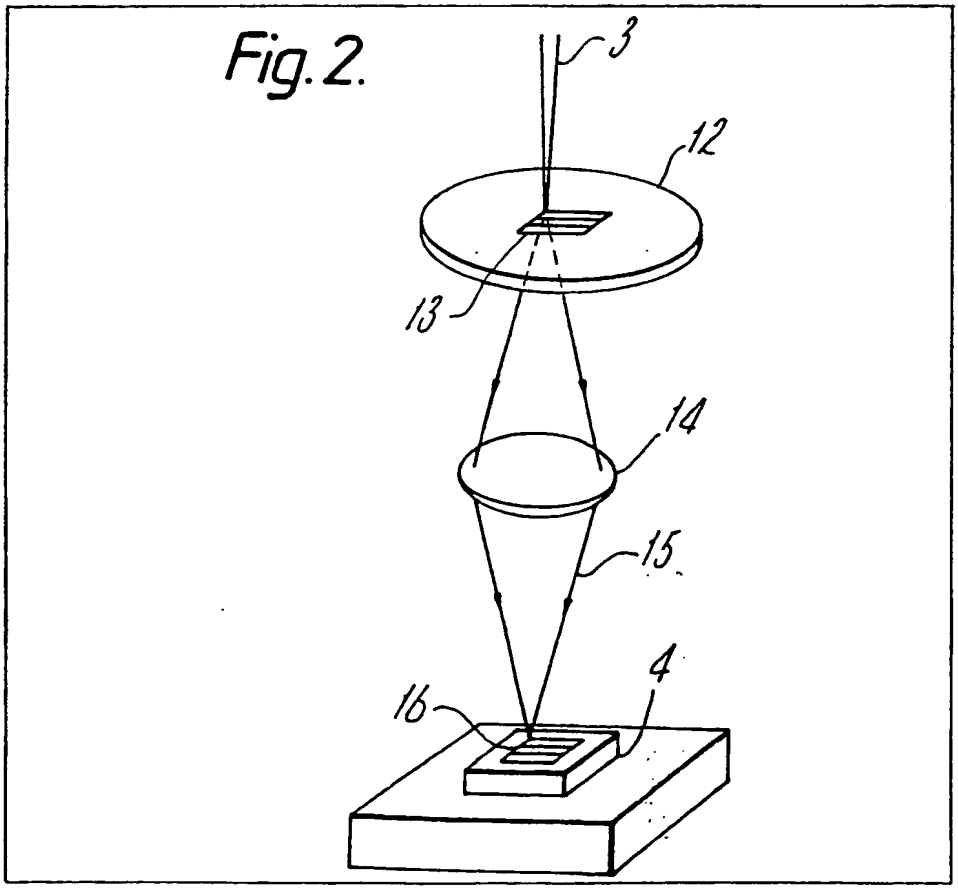

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Fig.1.

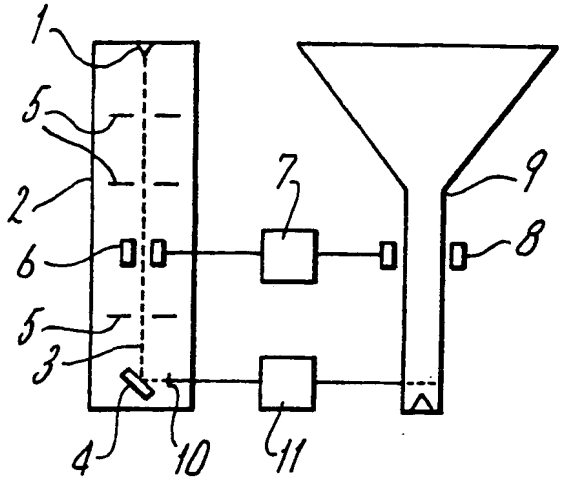


Fig.2.

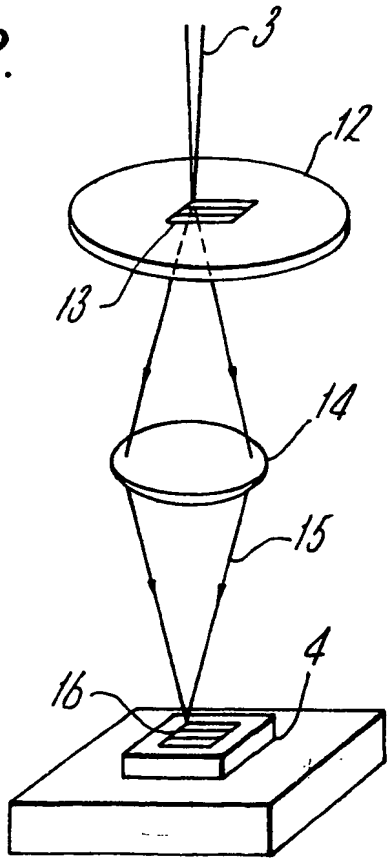
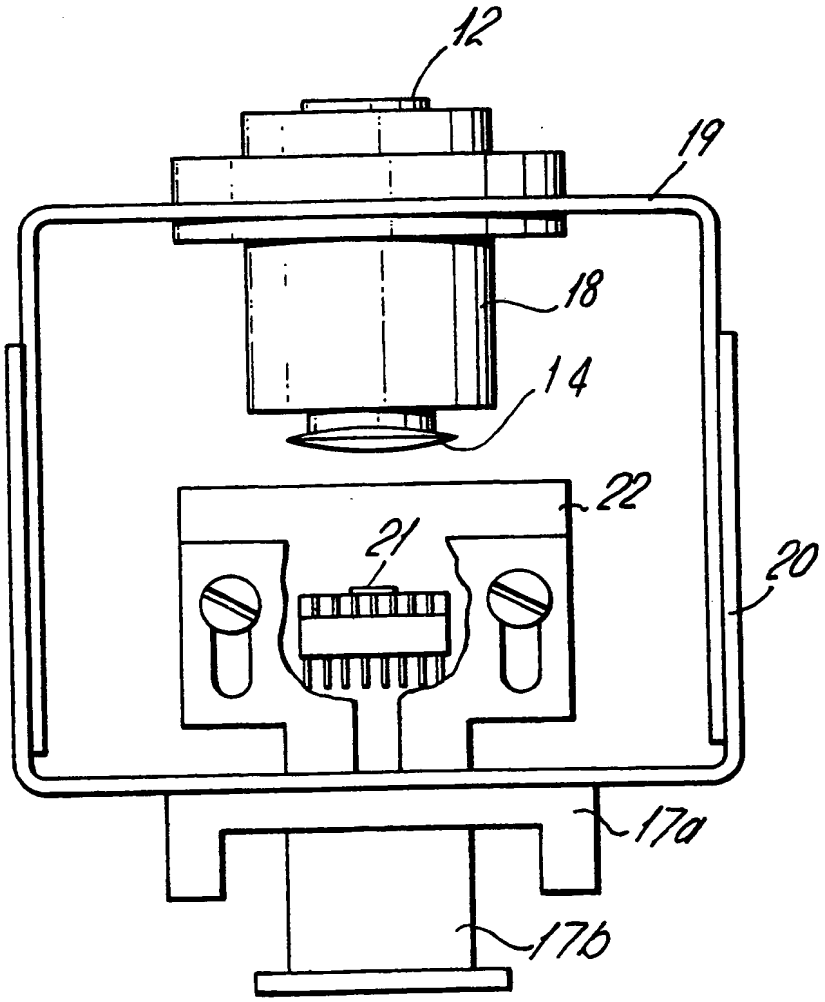


Fig. 3.



SPECIFICATION

Improvements relating to scanning electron and scanning optical microscopes

The use of scanning electron microscopes is now very widespread because of their versatility compared with other imaging systems. Apart from having a very large range of possible magnification, they provide very good resolution and a large depth of focus which produces images in a strikingly three-dimensional manner.

In a scanning electron microscope a fine beam of electrons is generated and focussed on the specimen to be viewed in an evacuated column, and the beam is caused to scan a raster over the specimen. The scanning electron beam incident on the specimen produces a signal which is detected and processed and subsequently used to modulate the brightness of a spot which is caused to scan a raster on a viewing screen (e.g. a video monitor) in synchronism with the raster executed by the electron beam. Variations in the specimen which produce variations in the detected signal are therefore translated into variations in the intensity of the scanning spot on the viewing screen, and an image of the specimen is thereby built up on the screen.

Depending on the specimen, there are in fact a number of different types of signal which can result from the impingement of the electron beam on the specimen and which can be detected and processed to form an image of the specimen. For example, the signal may comprise secondary electrons emitted from the specimen (emissive mode), or primary electrons back scattered from the specimen (reflective mode), the decrease in electric current flow from the specimen through an earth lead resulting from an increase in secondary emitted electrons or primary reflected electrons (absorbtive mode), the electrons which completely penetrate the specimen (transmission mode, generally suitable for thin specimens only), the change in specimen conductivity resulting in a change in electric current flowing through a pair of leads attached to the specimens (beam induced conductivity mode); the light emitted from the specimen (cathodo-luminescent mode), or the x-rays which are emitted from the specimen (x-ray mode). It is therefore usual for a scanning electron microscope to have detectors for some or all of these possible signals so that the operator can select the particular detector which he desires to use to obtain an image of the specimen. Furthermore, if the instrument is provided with an additional processing channel and viewing screen, it is possible to obtain and view different images from the same part of the specimen simultaneously.

This facility of having several possible imaging modes is a further example of the versatility of scanning electron micro microscopes. Another advantage of such instruments is the variety and control which can be achieved with the scanning rate and video presentation of image formation.

Scanning optical microscopes are also known in which a scanning light beam is used instead of a scanning electron beam. Apart from the fact that the ultimate resolution of a scanning optical microscope can never approach that of a scanning electron microscope because of the very much greater wavelength of light photons that kilovolt electrons, scanning optical microscopes should in principle have much the same advantages and versatility as scanning electron microscopes. In practice however, scanning optical microscopes have not been successful, mainly because of the relative inefficiency of the means which have been used for scanning the light beam, e.g. rotating mirrors or prisms, or specimen vibration. These mechanical precision engineering systems are expensive and unreliable, and achieve the desired resolution with difficulty.

However, scanning optical microscopes do offer some important advantages over scanning electron microscopes. Firstly the range of specimens which can be studied is much less restricted since specimens do not need to be scanned in vacuo and also do not need to be resistant to damage from exposure to an electron beam. For example, many biological specimens (particularly living organisms) and many modern semi-conductor devices (e.g. MOS devices) will suffer damage if studied in a scanning electron microscope, but not with a scanning optical microscope. Secondly, scanning electron miscroscopy is essentially a surface technique because of the very limited penetration depth of KV electrons. In contrast, depending on the nature of the specimen and the wavelength of the scanning light beam selected, scanning optical microscopes can be used ot study internal structures of specimens, provided these structures have different optical characteristics compared with the remainder of the specimen.

The present invention aims to provide an improvement over present forms of both scanning electron and scanning optical microscopes, and is based on the appreciation that both instruments can use the same image signal processing and display apparatus, and that a scanning electron beam can be converted to a scanning optical beam by means of a phosphor coated screen, or some other suitable luminescent device, in the path of the electron beam.

According to the invention, a scanning electron microscope is provided with a luminescent device which is capable of emitting light in response to incident electrons and which can be removably inserted into the path of the scanning electron beam so that the beam can be focussed on the device to produce light thereform, removable means for focussing the light from the device to form a scanning light beam focuss d on a specimen to be studi d, and a detector for a signal arising from the specimen in response to the incident light beam and arranged to be connected to the image signal processing and display system of the microscope, whereby the microscope operates as a scanning optical microscope when the luminescent device and light focussing means

are inserted in the electron path and operates normally as a scanning electron microscope when the luminescent device and light focussing means are removed.

In effect the invention provides a hybrid instrument which can be operated either as a scanning electron microscope or as a scanning optical microscope, with the attendant advantages of each. In addition, in the optical mode the instrument is an improvement over conventional scanning optical microscopes in that is possesses the scanning efficiency and versatility of the scanning electron microscope. A range of time dependent studies of a specimen can be carried out by varying the scanning rate of the electron beam or pulsing the beam using a beam blanking unit. Also, the wavelength of the scanning light beam can be changed simply by changing the luminescent device, whereas in a conventional scanning optical microscope it is necessary to change the laser light source. Usually the luminescent device will comprise a cathodoluminescent device in the form of a phosphor coated screen, and there is a wide range of phosphors having different wavelengths (usually between 2000 and 8000 Angstroms) and persistance values. For ease of removing or changing the luminescent device as desired, the microscope in accordance with the invention may have a holder such as a rotatable carousel or a reciprocable slide, which is arranged to carry a number of different luminescent devices and which is movable to shift each device into and out of the path of the electron beam.

One problem with obtaining the scanning light beam by electron excitation of a phosphor coated screen in the lack of light output from the screen compared with the laser source in a conventional scanning optical microscope. However, it should be noted that phosphors are available with conversion efficiencies of 25%, and with careful design of the optical focussing means the specimen should receive a significant proportion of the energy density available. In addition, comparatively large electron beam spot sizes may be used since the resolution of the optical system will in any case be limited to about one micron, which is also the tyical resolution for the electron beam induced conductivity mode commonly used when operating scanning electron microscopes. Thus the optical stimulation of the specimen can be approximately as energetic as electron beam stimulation. Futhermore, the resolution is not significantly different, at least when the instrument is operated in a beam induced conductivity mode.

However, if a greater light intensity is required for a particular study, this may be obtained, at least in the case of some cathodoluminescent devices, by applying an electric field across the device which induces an avalanche effect where the electron beam impinges on the coating and thus greatly increases the intensity of the light output. This is known as field enhanced luminescence. Futhermore, there are electroluminescent devices readily available which may be used with advantage in the instrument in accordance with the invention instead of a cathodoluminescent device, particularly those electroluminescent devices which incorporate laser action. For this purpose the instrument preferably includes means for generating an electric field across the luminescent device when it is inserted in the path of the electron beam, so that an electroluminescent device may be used, or field enhanced luminescence can be achieved when the device is a suitable cathodoluminescent device and is provided with suitable electrical contacts.

When the luminescent device is located in the path of the electron beam for operation of the instrument as a scanning optical microscope, it is or course essential that a vacuum can be maintained in the column above the device where the electron beam is generated and focussed. Whether the arrangement of the instrument is such that a vacuum can be maintained below the device is optional, although this will usually be the most convenient arrangement. In this case, when a specimen is to be studied which is incompatible with an evacuated environment, it will be necessary to place the specimen in a transparent air-tight cell. Alternatively, the specimen may be located outside the evacuated column and specimen stage of the microscope, the scanning light beam being reflected onto the specimen through a window from a mirror positioned in the specimen stage. This arrangement is particularly useful for studies of specimens under special conditions which cannot be realised easily or practically within the specimen stage. For example, the creation of a magnetic field within the specimen stage could interfere with the production and control of the scanning electron beam.

The means for focussing the scanning light beam on the specimen is preferably a lens, which may be single or compound. The lens need not form any part of the magnifying system of the microscope, since as with normal scanning electron microscopes magnification will be dependent primarily on the ratio of the sizes of the rasters scanned on the viewing screen and by the electron beam in the microscope, being controlled by adjusting the size of the electron beam raster by adjustment of the current through the scanning coils. However, if the lens is fixed to produce a raster on the specimen which is the same size as the raster scanned by the electron beam on th luminescent device, the image quality at very high magnification can, in the case of some phoshor coated screens, be marred by the effect of the grainy nature of the phophor coating. This will not of course occur with single crystal materials such as zinc tungstate and gallium arsenide. Nevertheless it is preferable to be able to adjust the lens position between the luminescent devic and the specimen in order to vary the ratio of th rasters scanned by the electron beam on the luminescent device and by the light beam on th

specimen, and for this purpose it is preferably also that the specimen can be adjusted in position towards and away from the luminescent device. Producing a smaller raster on the specimen than on the luminescent device has the effect of increasing the overall system magnification and resolution (at the expense of the depth of field), and thus will enable a given high magnification to be achieved using a large raster on the luminescent device which will not lead to adverse effects due to phosphor grain size when using a phosphor coated screen as the luminescent device. Furthermore, the reduced electron current density on the phosphor coated screen is less likely to cause degradation of the phosphor through burning.

In the same way as it will sometimes be desirable to change the luminescent device for different studies, it may sometimes be desirable also to change the lens. For this purpose the microscope may include a holder, such as a rotatable carousel or a reciprocal slide, which is arranged to carry a number of different lenses and which is movable to shift each lens into and out of it operative position. Focussing of each lens on the specimen is effected, as mentioned earlier, by movement of the lens and/or specimen towards or away from the luminescent device. If desired the lens aperture may be controlled by means of an iris, so that adjustment may be made between the intensity of the light beam incident on the specimen, resolution, and depth of field.

As mentioned earlier, a scanning electron microscope will usually have detectors for several different types of signal which may arise from the impingement of the electron beam on a specimen and which can be used to obtain an image of the specimen. Similarly there are a number of different possible signals which may arise from a specimen in reponse to the incident light beam in a scanning optical microscope, these mainly being reflected light, transmitted light, photoluminescence, and a beam induced electric current. Consequently the instrument in accordance with the invention will usually have a detector for one of these signals, and preferably will have detectors for all of these signals so that the instrument can be used as a scannig optical microscope in a beam induced conductivity mode, a photoluminescent mode, a reflection mode, or a transmission mode as desired.

The detectors for the reflection, transmission and photoluminescent modes will usually be photosensors which provide an output electric current in proportion to the intensity of light received, and the detector for the beam induced conductivity mode will comprise an amplifier and a pair of electrical leads for attachment to the specimen. Generally the detector or detectors which are provided for use when the instrument is operated as a scanning optical microscope will be separate from the detectors which are provided for use when the instrument is operated as a scanning electron microscope. Depending on the design however, it may sometimes be possible to use the same detectors for the luminescent and beam induced conductivity modes when operating as a scanning optical microscope and when operating as a scanning electron microscope.

One convenient way of realising the present invention is to provide a scanning electron microscope with interchangeable specimen stages, one for use when the microscope is to be operated normally as a scanning electron microscope, and one for use when the microscope is to be operated as a scanning optical microscope and which includes the luminescent device, the light focussing means, and the detector or detectors for signals arising from the specimen in response to the incident light beam. Indeed, in this way existing scanning electron microscopes can be converted to instruments in accordance with the invention simply by designing a suitably conversion specimen stage which will fit in the microscope in place of its own specimen stage.

According to a further aspect of the present invention therefore, a specimen stage which will fit in a scanning electron microscope in place of its own specimen stage to convert the scanning electron microscope to a scanning optical microscope comprises a specimen support, a luminescent device capable of emitting light in response to incident electrons and positioned so that in use it will be located in the path of the scanning electron beam of the scanning electron microscope, a lens for focussing the light from the luminescent device to form a scanning light beam focussed on a specimen to be studied, and a detector or detectors for a signal or signals arising from the specimen in response to the incident light beam and connectable to the image signal processing and display system of the scanning electron microscope.

The invention will now be described further with reference to the accompanying drawings, in which:—

Figure 1 is a diagram illustrating the design principles of a scanning electron microscope;

Figure 2 is a diagram illustrating the principle of converting a scanning electron microscope to a scanning optical microscope; and,

Figure 3 is a diagrammatic end view, partly cut away, of one form of specimen stage which is designed to fit in place of the existing specimen stage of a scanning electron microscope so that the microscope can be operated as a scanning optical microscope.

As illustrated in Figure 1, in a scanning electron microscope electrons are liberated and acclerated from a source 1 in an evacuated column 2, the electrons being directed and formed into a fine beam 3 focussed on a specimen 4 by suitable magnetic l nses 5. The electron beam 3 focussed on th specimen 4 is caused to scan a substantially square raster on the surface of the specimen by means of scanning coils 6 under the control of a scan generator 7 which similarly controls the deflection coils 8 of a cathode ray tube 9 so that a synchronous but much larger raster is scanned on the viewing screen of the

cathode ray tube 9 by the electron beam generated by the tube 9. As mentioned earlier in the specification; the electron beam incident on the specimen 4 can create a number of effects any one of which can be det cted and converted, if necessary, into an electric current proportional to the effect by means of a suitable detector 10. The electric current from the detector 10 is amplified by an amplifier 11 and used to modulate the intensity of the electron beam of the cathode ray tube 9. Consequently the brightness of any point in the raster scanned on the viewing screen of the cathode ray tube 9 is directly proportional to the intensity of the effect at the corresponding point in the raster scanned on the surface of the specimen 4, so that variations in the effect across the specimen will give rise to brightness variations which form an image on the viewing screen.

The principle behind the present invention wherein a scanning electron microscope can be converted to operate as a scanning optical microscope is illustrated in Figure 2. A phosphor coated screen 12 or other suitable luminescent device is positioned in the evacuated column in the path of the electron beam 3 above the specimen 4, and the electron beam 3 is focussed to scan its raster 13 on the screen 12. In addition, an optical system such as a lens 14 is positioned to focus the light emitted by the screen 12 as a result of the incident electron beam 3 to produce a beam of light 15 which is focussed on the specimen 4 and which scans a raster pattern 16 in synchronism with that scanned by the electron beam. In the symmetrical arrangement illustrated, the size of the raster 16 scanned by the light beam is the same as the raster 13 scanned by the electron beam, but by suitable asymmetric positioning of the lens 14, the size of the raster scanned by the light beam can be made larger or smaller than that of the electron beam as desired. When the electron beam is converted into a scanning light beam in this way, it is the light incident on the specimen which give rise to an effect which is detected and used to modulate the intensity of the electron beam of the cathode ray tube 9 to produce and image of the specimen. Depending on the effect and the instrument design, it may well be necessary to provide an additional detector for this purpose.

In general the specimen and detectors in a scanning electron microscope are mounted on a specimen stage which is removable from the column 2, and consequently the invention may be realised by constructing a replacement specimen stage which will fit in the column 2 instead of the original specimen stage of the microscope and which carries the luminescent device, lens, and additional detector or detectors necessary to enable the scanning electron microscope to operate as a scanning optical microscope as described with reference to Figure 2. An example of an experimental replacement (conversion) specimen stage which we designed to demonstrate the feasibility of the invention is illustrated schematically in Figure 3. The stage was adapted from the 100 series specimen stage of a Steroscan 11A scanning electron microscope, and is provided with an adaptor plate 17*a* and rail assembly 17*b* by which the stage can be inserted into the specimen chamber of a Cambridge Stereoscan 250 Mark 2 scanning electron microscope.

The luminescent device 12 and focussing lens 14 of the conversion stage are mounted in a telescopic tube 18 so that the device to lens distance is adjustable, and the tube 18 is mounted in a bridge piece 19 attached to the frame 20 of the original stage. The luminescent device 12 is formed by a phosphor (P11) coated screen, and the lens 14 comprises an X10 microscope objective, although these are readily changeable. The specimen tilt and rotation facilities of the original stage were discarded, but the XYZ translational movements were retained using an adjustable specimen mount 21 suspended from the original specimen support 22. The specimen position can thus be controlled externally by an operator with the stage in the microscope.

The stage is designed for operation only in the optical beam induced conductivity (OBIC) mode, and for this purpose the specimen mount 21 carries a pair of electrical leads (not shown) for connection to the specimen, the leads being arranged to connect by sliding contacts with the EBIC signal processing circuitry of the microscope when the stage is inserted in position. With the stage in position, the microscope has been used successfully in the OBIC mode to take images of several electronic devices which would be damaged by the electron beam if imaged using the scanning electron microscope in the ordinary way.

CLAIMS

1. A scanning electron mircoscope provided with a luminescent device which is capable of emitting light in response to incident electrons and which can be removably inserted into the path of the scanning electron beam so that the beam can be focussed on the device to produce light therefrom, removable means for focussing the light from the device to form a scanning light beam focussed on a specimen to be studied, and a detector for a signal arising from the specimen in response to the incident light beam and arranged to be connected to the image signal processing and display system of the microscope, whereby the microscope operates as a scanning optical microscope when the luminescent device and light focussing means are inserted in the electron path and operates normally as a scanning electron microscope when the luminescent device and light focussing means are inserted in the electron path and operates normally as a scanning electron microscope when the lurninescent device and light focussing means are removed.

2. A microscope according to claim 1, having detectors for enabling the microscope to operate as a scanning optical microscope in a beam induced conductivity mode, a photoluminescent mode, a reflection mode, or a transmission mode.

3. A microscope according to claim 1 or claim 2, including means for generating an electric field across the luminescent device when the device is inserted in the path of the electron beam.

4. A microscope according to any one of the preceding claims, in which the luminescent device is a cathodoluminescent device.

5. A microscope according to claim 4, in which the luminescent device is a phosphor coated screen.

6. A microscope according to claim 3, in which the luminescent device is an electroluminescent device.

7. A microscope according to any one of the preceding claims, having a holder which is arranged to carry a number of different luminescent devices and which is movable to shift each device into and out of the path of the electron beam so that the device can be readily removed or changed as desired.

8. A microscope according to any one of the preceding claims, in which the light focussing means comprises a lens.

9. A microscope according to claim 8, in which the lens is adjustable in position axially towards and away from the luminescent device.

10. A microscope according to claim 8 or claim 9, having a holdler which is arranged to carry a number of different lenses and which is movable to shift each lens into and out of its operative position so that the lens can be readily removed or changed as desired.

11. A microscope according to any one of claims 8 to 10, having an iris for adjusting the aperture of the lens.

12. A microscope according to any one of the preceding claims, having interchangeable specimen stages, one for use when the microscope is to be operated normally as a scanning electron microscope, and one for use when the microscope is to be operated as a scanning optical microscpoe and which includes the luminescent device, the light focussing means, and the detector or detectors for signals arising from the specimen in response to the incident light beam.

13. A specimen stage which will fit in a scanning electron microscope in place of its own specimen stage to convert the scanning electron microscope to a scanning optical microscope, the converting specimen stage comprising a specimen support, a luminescent device capable of emitting light in response to incident electrons and positioned so that in use it will be located in the path of the scanning electron beam of the scanning electron microscope, a lens for focussing the light from the luminescent device to form a scanning light beam focussed on a specimen to be studied, and a detector or detectors for a signal or signals arising from the specimen in response to the incident light beam and connectable to the image signal processing and display system of the scanning electron microscope.

14. A specimen stage according to claim 13, having detectors for enabling the scanning electron microscope to operate as a scanning optical microscope in a beam induced conductivity mode, a photoluminescent mode, a reflection mode, or a transmission mode.

15. A specimen stage according to claim 13 or claim 14, in which the lens is adjustable in position axially towards and away from the luminescent device.

16. A specimen stage according to any one of claims 13 to 15, in which the specimen support is adjustable in position axially towards and away from the luminescent device.

17. A specimen stage according to any one of claims 13 to 16, in which the specimen support is adjustable laterally in two orthogonal directions.

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